A momentum microscope views few body dynamics

R.Dörner[1], M.H. Prior[2], C.L. Cocke[3], Th. Weber[1], O. Jagutzki[1], L. Spielberger[1], V. Mergel[1], A. Czasch[2,1], M. Achler[1] , H. Bräuning[2,3,4], R. Moshammer[5], J.M. Feagin[6], A. Landers[7,3], T. Osipov[3], A. Bräuning-Demian[1], N. Berrah[7], J.D. Bozek[2], G. Meigs[2], T. Warwick[2], H.Schmidt-Böcking[1]

[1]University of Frankfurt, 60486 Frankfurt, Germany
[2]Lawrence Berkeley National Laboratory, University of California, Berkeley, Berkeley CA 94720, USA
[3]Kansas State University, Manhattan, KS 66506, USA
[4]University of Giessen, 35390 Giessen, Germany
[5]University of Freiburg, 79085 Freiburg im Breisgau, Germany
[6]California State University, Fullerton, Fullerton, CA 92834, USA
[7]Western Michigan University, Kalamzoo, MI 49008, USA

How has nature created all the wonderful complexity surrounding us from such simple ingredients as positively charged nuclei and negatively charged electrons? What coordinates all the subtle motions and changes which animate our world on a microscopic level? The general answer to this is termed dynamical electron correlation. It is the pure fact that electrons mostly change their patterns of motion, more precisely their wavefunctions, not individually and independently of each other , but in a highly correlated fashion. This is determined by the complex, many particle, momentum exchange, via the Coulomb forces, between the charged particles (electrons and ions). This momentum exchange is constrained by quantum mechanical symmetry conditions imposed on all composite systems by their total angular momentum and parity.

A long term project at the ALS is yielding new insight into this fundamental problem of electron correlation by investigating paradigmatic simple few body processes in all available detail. To do this, a novel momentum space microscope (termed COLTRIMS) end station is used. It has been developed by a collaboration among University Frankfurt, Kansas State University and LBNL. This device provides multi-dimensional images of the correlated momenta of all charged particles after photo-fragmentation of an atom or small molecule. Subatomic resolution and high detection efficiency is achieved for each electron and ion no matter in which direction they may be moving.

Using this unique tool we have investigated the ejection of two electron from Helium (ref 1,2) and Neon. More recently we have applied this technique to study the complete fragmentation of a hydrogen (deuterium) molecule by absorption of a single photon. The final state for this process consists of two protons and two electrons. The momentum vectors of each of the four particles have been measured in coincidence. The fact, that a single photon can couple to two electrons at all is a remarkable consequence of electron correlation. In a world of isolated, un-correlated electrons, the probability for coupling one photon to two electrons would be zero.

After absorption of the photon the two electrons are emitted very quickly. On a much longer time scale the two heavy nuclei then fly apart back to back along the molecular axis because of the repulsive Coulomb force between them. Thus detecting the two nuclei yield the orientation of the molecular axis at the instant of ionization. With this trick one can map the correlated emission pattern of the two electrons from a “fixed in space” molecule.

In a first experiment at the old beamline 9 we measured the energy and angular distribution of one of the two electrons with respect to the two heavy nuclei (ref. 3). Then, in two successive experiments at BL 7 finally both electrons and both nuclei were measured. This is the first time that the correlated electron emission from a molecule has been mapped in all detail. Astonishingly the gross features of the two electron wave functions do not depend strongly on the molecular orientation and are somewhat similar to emission pattern from a helium atom. The two new molecular effects to be seen are interference due to the two indistinguishable centers of the molecule and the consequences of a transfer of angular momentum from the electronic to the nuclear wave function.

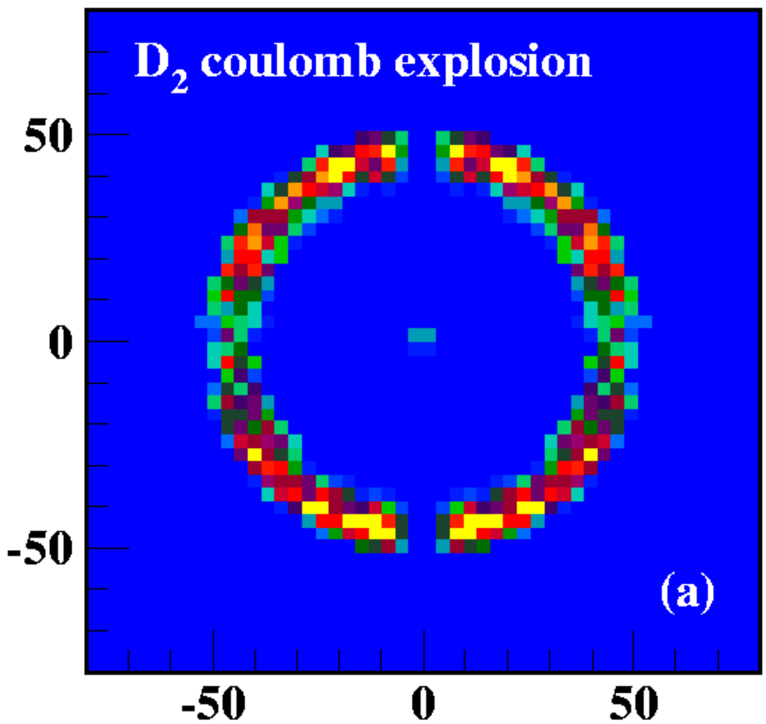

Figure 1. Momentum distribution of the D+fragments from photo double ionization of D_2 by 58.8 eV linear polarized light. The electric field vector is horizontal, the light propagates in the vertical direction. The gap in the "ring" is caused by inability to separate two ions arriving at the detector at nearly the same time.

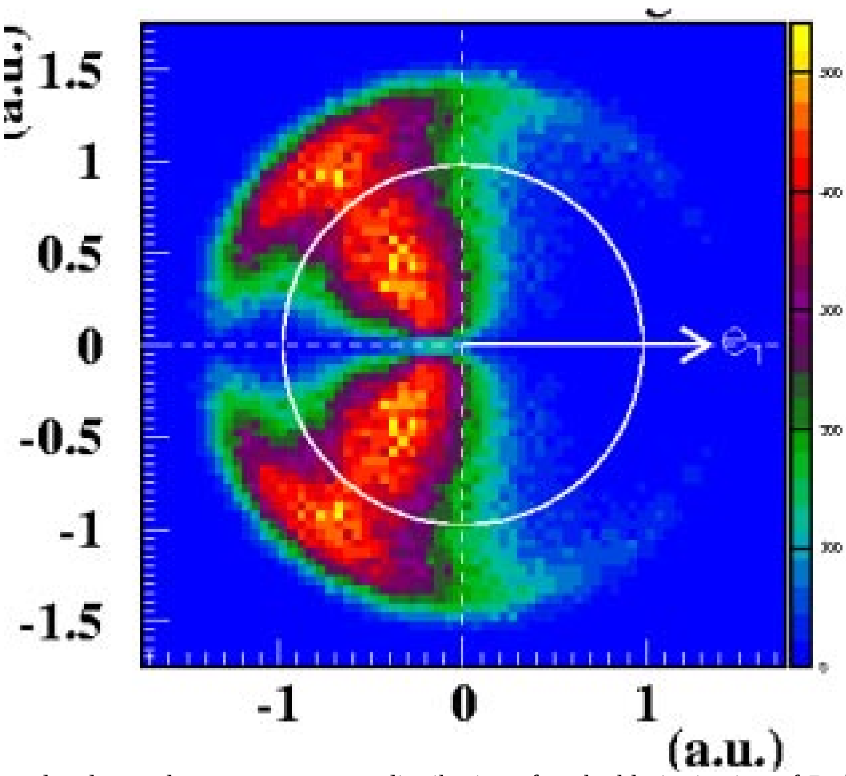

Figure 2: Correlated two electron momentum distribution after double ionization of D_2 by photons 25 eV above the double ionization threshold. The momentum vector of one electron points along the horizontal axis to the right (arrow), the momentum distribution of the second electron is shown. Electron repulsion is responsible for the dominant emission of the two electrons into opposite half spheres. The node for back to back emission is a result of the odd parity symmetry of the final state electron wave function. The data are integrated over all orientations of the molecule and all directions of the polarization axis. This plot is only one of many ways to visualize results of these measurements. The power of the technique allows the investigator to view the correlations among the particle momenta without enforcing a priori restrictions on any of them.

REFERENCES

1. R. Dörner, H. Bräuning, J.M. Feagin, V. Mergel, O. Jagutzki, L. Spielberger, T. Vogt, H. Khemliche, M.H. Prior, J. Ullrich, C.L. Cocke and H. Schmidt-Böcking. Photo double ionization of He: Fully differential and absolute electronic and ionic momentum distributions. Phys. Rev. A **57** (1998) 1074.
2. H. Bräuning, R. Dörner, C.L. Cocke, M.H. Prior, B. Krässig, A.S. Kheifets, I. Bray, A. Bräuning-Demian, K. Carnes, S. Dreuil, V. Mergel, P. Richard, J. Ullrich and H. Schmidt-Böcking. Absolute triple differential cross sections for photo double ionization of helium - experiment and theory. J. Phys. B **31** (1998) 5149.
3. R. Dörner, H.P. Bräuning, O. Jagutzki, V. Mergel, M. Achler, R. Moshammer, J. Feagin, T. Osipov, A. Bräuning-Demian, L. Spielberger, J.H. McGuire, M.H. Prior, N. Berrah, J. Bozek, C.L. Cocke and H. Schmidt-Böcking. Double photo ionization of spatially aligned D_2. Phys. Rev. Lett. **81** (1998) 5776.

This work was supported by BMBF; Alexander von Humboldt-Stiftung, Habilatenden Programm; Office of Science, Office of Basic Energy Sciences, Chemical Sciences Division, U.S. Department of Energy.

Principal investigator: Reinhard Dörner, University of Frankfurt. Email: doerner@hsb.uni-frankfurt.de. Telephone: 049 69 798 24218.